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REPORT ON INSECT INFESTATION OF STORED CACAO

Prepared for the Empire Marketing Board's Committee on Infestation of Stored Products.

By

J. W. MUNRO, M.A., D.Sc.,

and

W. S. THOMSON, M.A.,

Imperial College of Science and Technology, London.

DECEMBER, 1929

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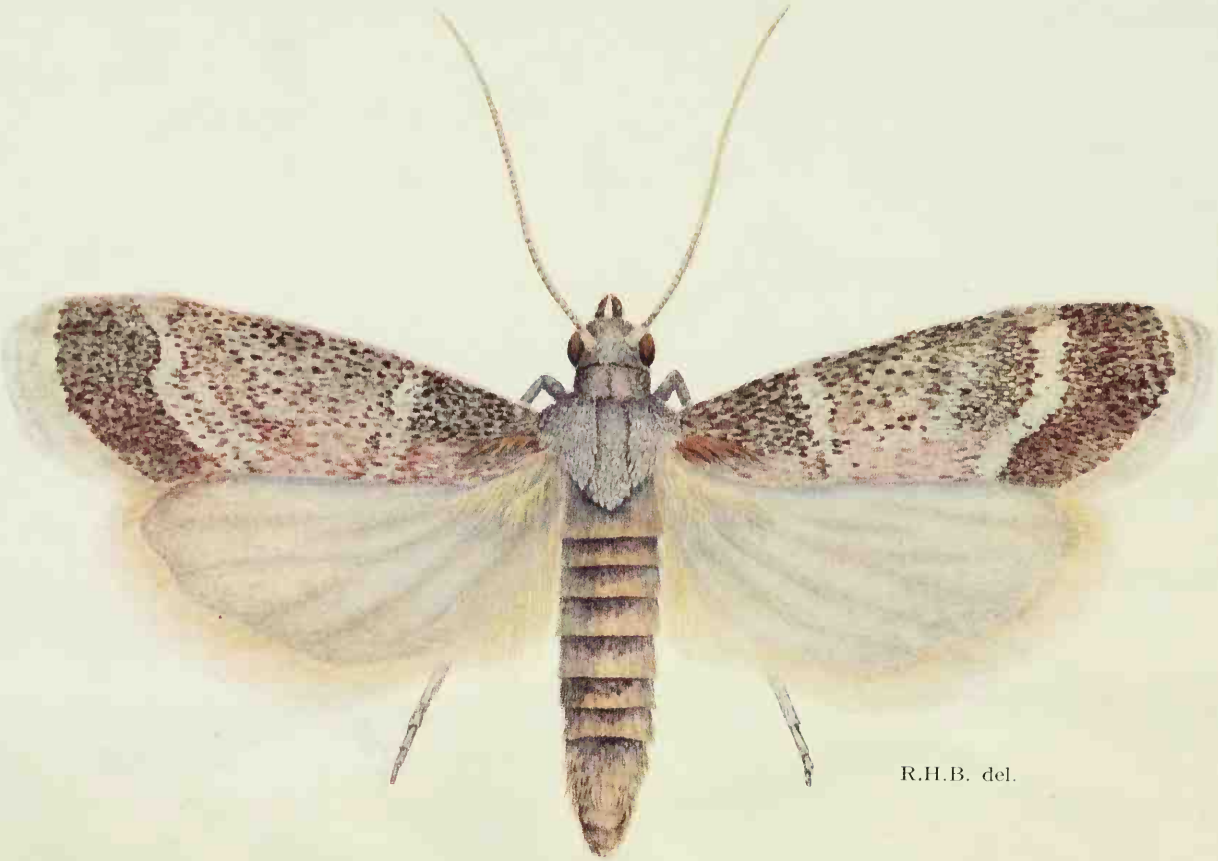

Plate I. *Ephestia elutella* Hb., adult. × 9 (approx.)

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PREFATORY NOTE.

This Report dealing with a preliminary survey of the insect conditions prevailing in cacao stores in certain wharves and docks in London has been prepared for the Empire Marketing Board's Committee on Infestion of Stored Products by Mr. W. S. Thomson, under the direction of Dr. J. W. Munro, Assistant Professor of Entomology in the Imperial College of Science and Technology.

Since the preliminary survey was started, the Board has by a series of grants made to the College enabled that Institution to establish at Slough a research laboratory for the special conduct of Stored Products Research.

At present the research in progress is concentrated on the study of the insect problems affecting cacao and dried fruits and of the problems presented by the occurrence of moulds in cacao and copra, but other products are also receiving attention and the whole field of stored products entomology and mycology will be explored as time and opportunity permit.

The Report affords a useful indication of the nature and extent of the insect problems presented by stored cacao. In particular it shows that the control and prevention of the losses now caused by cacao insects can be attained only by co-operation on the part of all concerned, because insect infestation occurs throughout all stages of the cacao industry.

The most important pest of cacao, the moth *Ephestia elutella*, is now established in the wharves and stores in this country, but even so its numbers are regularly augmented by introduction in shipments from abroad and it is scarcely reasonable to expect wharfingers and warehousemen to take measures to keep their premises free from the moth when every consignment of cacao constitutes a source of re-infestation.

This aspect of the problem is receiving special consideration, and it is hoped that one effect of the publication of this Report will be to call attention to the actual conditions prevailing in the London docks, and to induce the oversea producers and exporters to consider whether all is being done on their part to ensure the shipment of clean cacao. Obviously the general problem will be dealt with by co-operation of all parties, both at home and overseas.

REPORT ON INSECT INFESTATION OF STORED CACAO.

I. INTRODUCTION.

WITHIN recent years the problem of insect infestation of cacao in store in this country has assumed increasing importance. While the direct loss of cacao caused by the depredations of insect pests is small, the indirect losses are sometimes of considerable magnitude.

Cacao insects are transferred from the docks to chocolate factories inland; this may result in the occurrence of larvae or caterpillars in boxes of manufactured chocolates, a circumstance which would seriously affect the prestige of the firm concerned.

Cacao, of which more than 15 per cent. is infested by insects and is mouldy, is rejected at the U.S. Ports by the Food, Drug and Insecticide Administration of the U.S. Department of Agriculture, who are charged with the enforcement of the Food Laws. The entrance of cacao in which over 10 per cent. of mould is present, is also prohibited. An account of the provisions of the Food Laws is given by Schwarz (38) and by Culham and Scott (8).

Certain cacao insects, notably the *Ephestia* moths, affect other products stored in proximity to cacao, and so are a matter of concern to the wharfingers and brokers. For instance, the wandering of *Ephestia* larvae to such a product as arrowroot sometimes seriously reduces the value of this product, and may in extreme cases cause it to be unmarketable. Although the larvae do not consume arrowroot, they may soil it with web while searching for a suitable place to pupate.

Nature and Extent of the Problem.

The problem of insect infestation of stored cacao has three main aspects :—

(*a*) Infestation in the exporting country ;

(*b*) Infestation in the wharves and warehouses in the importing country ;

(*c*) Infestation in the cocoa and chocolate factories in the importing country.

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The object of this survey was to study the second of these aspects ; mention may be made, however, of work which has been done or is now in progress in connection with the other two.

Infestation in the Exporting Country.

Schwarz (38) has surveyed the cacao industry of the Gold Coast, Nigeria, Cameroons and Fernando Po in some detail, with reference to the causes and prevention of mould in cacao. Should the recommendations made by him be carried out, they will probably result also in a distinct diminution in insect infestation.

He deals comprehensively with the industry in West Africa, describing the cacao belt ; the system of land tenure ; forest reserves as a protection for the cacao trees from excessive sunlight ; the work of the Department of Agriculture in educating the natives ; the preparation and handling of the crop ; transportation of the crop from up-country to the ports ; shipping the crop ; experimental work which is being carried out at Aburi on fermentation and moisture-content of the beans ; and finally, proposed legislation.

For drying purposes the fermented cacao is spread out, either on bamboo mats or on tarpaulins, which are raised above the ground. The beans are exposed for about five days, but are protected from the sun for part of the first day in order not to bake the husks ; otherwise drying might be retarded. They are further protected in the event of rainy weather setting in. After drying, the cacao is bagged and sent down to depots, where, if it is found to have been insufficiently dried, it may be further exposed to the sun, and afterwards re-bagged.

In the Gold Coast the bags, when ready for shipment, are stored either in warehouses or, if such accommodation be inadequate, on the beach. When storage on the beach is necessary, the piles are usually supported on a platform raised about a foot from the ground. Tarpaulins are used as a protection from rain.

At the present time, transport from the shore to the ship is effected by means of surf boats, with the result that considerable damage from wetting frequently occurs and gives rise to a high proportion of mould in the consignment. If, however, as seems probable, Takoradi becomes the principal port in the Gold Coast, both storage and shipping conditions will be greatly improved, with consequent benefit to the cacao industry.

It will be seen from the foregoing that there is ample opportunity for insect infestation to occur in the country of origin, particularly on the drying-stages. Mr. W. H. Patterson, Senior Entomologist at Aburi, Gold Coast, in a letter to " Tropical Life " (32) lays emphasis on this point, and states that " the trouble does not start with the stores here ; it actually originates in the drying-stages ". He is of the opinion that the Anthribid beetle, *Araecerus fasciculatus* De G., is a greater enemy of cacao in West Africa than the Phycitid moth *Ephestia elutella*, Hb., which is the more common pest of cacao in general, and it is with reference to the beetle rather than to the moth that the statement quoted is made. Nevertheless, it is probable that in regard to *Ephestia*, the starting point of the infestation is the same, i.e. the drying-stages. Although sometimes the one insect seems to predominate and sometimes the other, generally *Ephestia* is undoubtedly the more important in relation to the infestation of cacao. It may be that *Araecerus*, which bores into the beans, serves as an auxiliary of *Ephestia*, whose larvae can successfully attack beans only when the shell or husk is broken. In West African cacao, however, the incidence of mould is more widespread and important than that of any insect.

Knapp (21) enumerates several insects, among them three species of *Ephestia*, infesting stored cacao, and mentions not only the drying-stages and storage sheds, but also the cacao trees and pods as possible sources of infestation in the countries of origin. In his opinion the trees and pods are important as providing a possible habitat from which *Araecerus* might infest cacao in the drying-stages. He further mentions the occurrence of *Ephestia elutella* Hb. as a pest of cacao in store in Java ; and Granato (16) records the same moth as attacking cacao-pods in Brazil—an interesting point worthy of further investigation.

Apart from the instances just referred to, little work seems to have been done hitherto on the incidence of insect infestation of cacao in the exporting countries.

Infestation in Chocolate Factories.

An investigation of the infestation of chocolate factories by *Ephestia* moths has been carried out by the Cocoa, Chocolate, Jam, Sugar and Confectionery Trades' Research Association, and has shown that no stage of *Ephestia* is able to survive the manufacturing processes which are undergone by the cacao at the factory. This limits the problem

of the manufacturers to one of protecting their goods from risk of infestation between the time of finishing and distribution from the factory. There is, of course, always a possibility that the finished goods may become infested during transport or in the retailer's store through contact with infested material, e.g. cereals, dried fruit and nuts.

In Germany, Zacher (45) has done interesting work in connection with the incidence of infestation by *Ephestia* in chocolate factories, and a short summary of part of his paper on this subject may be of interest. The arrangement of the various processes connected with the manufacture of chocolate from cacao is described as follows—on the top floor of the factory are the raw cacao stores and the husking and winnowing machines ; on the floor below are the roasting and grinding machines ; on the next floor the mixing machines, and below this the finishing and packing rooms. Corresponding to this arrangement, Zacher has found the number of *Ephestia* moths present diminishing rapidly with the increasing distance from the raw material. He states that any larvae which may be feeding in the beans will almost certainly be killed during roasting ; that any eggs which may be laid on the beans after roasting are destroyed during grinding and mixing. He infers that if, in spite of this, evidence of infestation appears in the finished article, it may be put down either to the presence of eggs or other stages of the insect in nuts used in making nut-chocolate, or to the presence of isolated moths in the packing rooms. Having discussed in some detail the points just noticed, he makes the recommendation that where possible special chambers should be constructed, preferably at some little distance from the factory, for the storage of cacao beans prior to roasting. Just sufficient quantities to satisfy the needs of the moment should be brought into the factory, and immediately roasted. The major point which he brings out, however, is that infestation in the factories arises in the first instance from the presence of *Ephestia* in the cacao beans, which may have been infested in the country of origin or re-infested while in store at the ports. This is in accord with experience in this country.

Infestation at the Wharves and Warehouses in the Importing Country.

American literature contains few references to the occurrence of either *Ephestia elutella* or *Araecerus fasciculatus* in cacao, although there are many papers relating to the occurrence of *Ephestia elutella* in other products.

Interest in insect infestation problems has been aroused in Germany. In the "Laboratorium für Vorrats- und Speicher-schädlinge" the incidence of stored-products pests in the warehouses and factories has been studied since 1917, under the supervision of Dr. F. Zacher. As in other countries, the infestation by insects of cacao and of the various types of confectionery manufactured from it, is an important problem in Germany.

Zacher (45) has recently reviewed the incidence of *Ephestia* in Germany in the warehouses, at the ports, and in the chocolate factories. In addition to a brief account of the biology of *E. elutella,* in which he describes the eggs, larvae, pupae and adults, he gives a list of products in which the larvae have been found feeding, and outlines possible control measures. Since frequent reference to his work will be made in this report, further discussion is unnecessary here, beyond indicating that many of his results coincide almost exactly with those obtained during the present survey.

II. OBJECTS OF THE PRESENT INVESTIGATION.

The objects of the investigation were to determine which insects are chiefly responsible for the infestation of cacao ; to assess the extent to which infestation takes place at different seasons and in cacao from different countries ; to define the extent to which re-infestation occurs in the warehouses in this country ; and to ascertain the extent to which infestation is preventible.

It was thought advisable to divide the work into two parts. A preliminary survey was undertaken in order to obtain a general knowledge of the conditions prevailing in wharves and warehouses. This was followed by a detailed survey, in order to study more intensively the insects and storage conditions affecting cacao in particular.

Preliminary Survey.

The various warehouses at which the survey was carried out differ somewhat in size, and, therefore, in the floor-space available for storage purposes, but agree in the main in construction. There are up to five floors in each warehouse ; the height of a floor varies from about 8 to 10 feet. In the outer wall of each floor is a "loophole", consisting of a pair of doors which open inwards, and below them a hinged wooden flap which is supported by chains and

which can be opened outwards. When the loop is open, goods can be taken into or out of the floor by means of a block and tackle. The doors leading to landings or from one floor to another are usually of iron, and when doors and loop are open, as frequently happens, there is often a strong draught blowing through the floor. In addition to the loops and doors, there are frequently two windows, portions of which can, in some cases, be opened. In certain floors of one warehouse visited there are also loop-holes in the actual flooring; these admit of internal communication and allow transfer of goods from floor to floor without using the outside loops or the stairs.

In one warehouse where cacao is stored, the stairs leading from one floor to another are placed outside the building; in another, the stairways are within the floors themselves, there being no landings; in a third, except in one section, where a similar internal stair exists, the stairways run up between the sections, and the doors of the various floors open on to landings.

Lighting arrangements differ considerably as between warehouses. In some, the windows of each floor are large, and the walls and ceilings are kept whitewashed. As a result, the lower floors are almost as well lit as the top ones, which possess skylights as well as windows. In others, the windows are smaller, and neither walls nor ceilings are whitewashed, except on certain floors; the top floors are fitted with skylights, and here the light is good, but the lower floors are often very badly lit, some indeed, being almost pitch-dark. As most floors in this type of warehouse are smaller than those in the other, the piles of bags stored tend to be higher. When a floor is full the windows are often obscured, so that the only effective light is that which illumines a small area round the loop, should this happen to be open. In some parts of the warehouse, however, artificial light is provided.

Only one of the warehouses under consideration specialises to any marked degree in the storage of any one product—in this case, cacao. Others specialise to a lesser extent, confining themselves in the main to such products as cacao, spices and coffee, and as far as possible setting aside particular floors for the storage of individual products. It is rarely possible, however, to consider the different floors independently so far as insects are concerned, because the insect conditions found on one floor are usually also to be found on the next. Slight variations in the fauna of different floors are due as a rule merely to the different nature of the products in store at the moment. Cacao and nutmegs have the richest fauna, and coffee the poorest.

In considering the question of the control of insects in these warehouses a number of factors must be taken into account: for example, what species of insects found are those especially associated with cacao; whether these also attack other products stored with cacao; whether any insects which attack other products also attack cacao; whether exotic cacao insects survive the English winter, and if so, in what stage and where they hibernate; what part is played by dirt and rubbish in insect infestation, and particularly in re-infestation, where this occurs; in what way infestation is affected by lighting and ventilation; and whether damage caused by rats has any effect on infestation.

With the object of elucidating some of these questions, general inspections of different products and of the warehouses themselves were made, and during the period October, 1927, to March, 1928, much insect material was collected and many useful observations were recorded.

In this way a knowledge was gained of the fauna of the warehouse in general, and in the course of time many of the insects at first classed only in a general way became assignable to their proper place in the ecology of the warehouse. By this means some of the questions regarding the relationship of certain insects to certain products had been cleared up before the detailed survey was begun.

For example, it has been confirmed that the most important insect affecting cacao is the Phycitid moth, *Ephestia elutella*, Hb.; that nutmegs are very seriously infested by the Anthribid beetle, *Araecerus fasciculatus*, de G., with which are associated a number of other insects; and that the beetles *Caulophilus latinasus* (Cossonidae) and *Lasioderma serricorne* F. (Anobiidae) are major pests of ginger. There was an indication, which was afterwards confirmed, that another moth, *Corcyra cephalonica*, Staint, is capable of living both on cacao and nutmegs. It was found that *Ephestia elutella* is capable of withstanding very cold weather, for shortly after the cold spell at Christmas, 1927, larvae were found hibernating under some paper which had not been disturbed for several months. These larvae were in a healthy condition. On the other hand, adult *Araecerus* beetles very soon die unless kept under warm conditions, and it would appear that our winter is too cold for them. In dirt and rubbish, consisting chiefly of dust and particles of various products, including whole

cacao-beans, *Ephestia* species, the beetle *Ptinus tectus*, Boield, and allied species, and small beetles of the genus *Laemophloeus* were found breeding. Although the preliminary survey did not provide any definite indication that re-infestation of cacao actually takes place, nevertheless it showed that conditions on the whole are favourable to re-infestation, in that *Ephestia* larvae are perfectly capable of withstanding an average winter in this country.

Other interesting points were noted during the survey. Two examples may be given to show the extraordinary numbers of insects which are sometimes introduced with an imported product. On one floor where cacao was stored, the walls, ceiling, windows and bags were covered with a thick silken web, spun by thousands of fully-fed *Ephestia* larvae as they left the cacao and wandered through the floor in search of suitable places to hibernate and afterwards to pupate. When frequent cleaning is not carried out, this web, added to by succeeding generations of larvae, attains quite a remarkable thickness and strength. A strip of web some 10 or 11 inches in length by 3 or 4 inches wide was removed from a wall at one pull, and web was seen hanging in festoons from the bags. The other example is somewhat different. In the autumn of 1927, some barrels of dry ginger were stored at one of the warehouses. In October or November of that year, the floor, barrels and adjacent bags of cacao were found to be swarming with the adults of the Cossonid beetle *Caulophilus latinasus* Say. *Caulophilus*, though probably always present in small numbers, has not appeared in such quantities since.

Many insects which cannot be associated with specific products occur in the warehouses. The preliminary survey has shown that some beetles, such as members of the families Dermestidae and Cleridae, are definitely predaceous on other insects, while others, such as *Cryptophagus* spp., small beetles of the family Cryptophagidae, are associated with the various moulds which occur on damp walls, but may in some cases be attracted by mould in products such as cacao. These two classes are not strictly assignable to any product and are thus best described as " general " feeders. Other insects occur more or less accidentally and come into the warehouses from outside. These include Muscid, Tachinid and Drosophilid flies ; the beetles *Lyctus brunneus* Steph. and *Dinoderus minutus* F., which occur in small numbers and which are probably associated with some of the less important products ; large tropical species whose habits do

not bring them in any way into contact with stored products (e.g. the Scarabeid beetle, *Phileurus didymus* L.), and which almost invariably occur as isolated specimens and are nearly always dead on arrival in London ; and finally insects which are known abroad as stored products pests but which occur only rarely in England.

Apart from these is a group which comprises those insects which, though not themselves strictly assignable to any product, are parasitic upon other insects associated with some particular product. Of these the Braconid wasp, *Microbracon hebetor*, Say., which is an important parasite of *Ephestia elutella*, is a good example.

In all, some thirty species of insects have been found in association with stored cacao, but at present only three of these are known to be of much importance, namely : *Araecerus fasciculatus* De G., *Corcyra cephalonica* Staint., and *Ephestia elutella* Hb. These three will be dealt with later in the report, but it is not proposed to enter into any further discussion of insects which normally occur in warehouses where cacao and spices are stored, since a detailed account of these insects is at present being prepared for publication.

Detailed Survey.

The Port of London was chosen for the detailed survey, partly on account of convenience and partly because facilities for routine examinations already existed. Detailed records of as many shipments of cacao as possible were kept, and as large a sample of each shipment was examined as circumstances permitted. The details recorded were date of landing, date of examination, country of origin, mark, name of ship, general condition of the beans (presence of broken and mouldy beans, odour), and the estimated extent of infestation by *Ephestia elutella*, *Araecerus fasciculatus*, and other insects. (It may be mentioned that whenever space permits, the bags of cacao are temporarily stood on end against one another to facilitate sampling ; it is contrary to usual practice to pile the bags before samples have been drawn.)

The detailed survey was begun at the end of April, 1928, and the report deals with the results obtained between that date and December, 1928. During this period some 88 shipments of cacao were examined, and these were distributed between two wharves, except in the case of one shipment of Gold Coast cacao.

TABLE I.

Number of Consignments of Cacao examined between 24th April and 19th December, 1928.

Country.	I. No. of Consignments examined.	II. Total No. of Bags in the Consignments.	III. No. of Bags examined.
Cameroons	4	1,685	136
Ceylon	7	554	143
Dominica	2	27	5
Gold Coast	10	12,439	392
Grenada	12	6,354	1,234
Jamaica	2	38	9
St. Lucia	10	1,078	295
St. Vincent	3	86	12
Samoa	4	1,299	200
Trinidad	7	1,235	292
Brazil	3	1,450	108
Costa Rica	11	371	94
Ecuador	5	1,275	127
Panama	1	52	52
Venezuela	7	1,115	182

The figures given in column III of Table I represent a careful, though limited examination of about 3,270 bags of cacao. In addition to these, small samples from about 750 bags were also examined, in cases where the bags had to be piled and could not be completely opened up. (When the bags are piled a small semi-circular cut is made at any convenient point ; from the hole thus formed the sample is extracted by means of a scoop, the cut being sown up again afterwards.)

III. PRINCIPAL INSECTS FOUND DURING THE SURVEY AND THEIR RELATIVE IMPORTANCE.

There are three insects to be considered in relation to cacao :—

(i) *Araecerus fasciculatus* De G.

(ii) *Corcyra cephalonica* Staint.

(iii) *Ephestia elutella*, Hb.

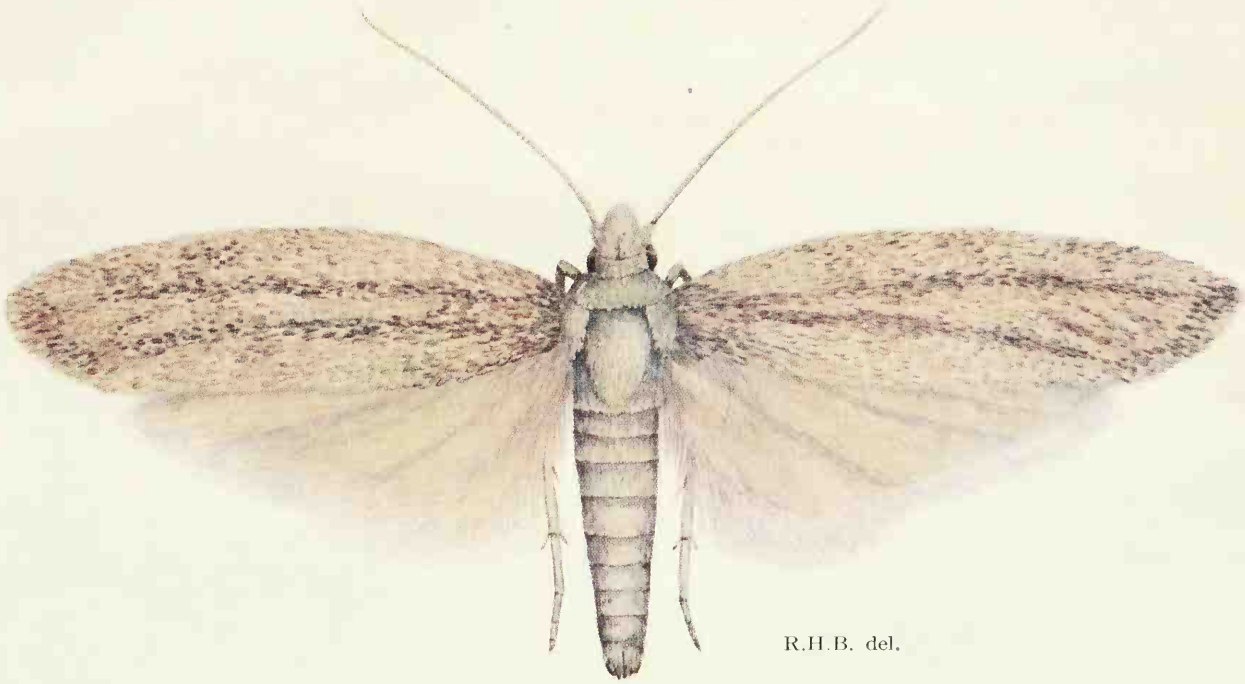

Plate II. *Corcyra cephalonica* Staint., adult. × 8 (approx.)

(i) *Araecerus fasciculatus* De G.

Belonging to the family Anthribidae, this beetle is chiefly of importance in relation to cacao because of its occurrence in beans from the Gold Coast, where, it will be remembered, Patterson (*loc. cit.*) records it as causing considerable damage on the drying stages.

It is widely distributed in tropical countries, but appears to possess little resistance to cold, and very soon becomes sluggish and dies when it arrives in England during the cold weather. It survives the summer months, although on a cool day it is very much less active than usual ; and if the windows of a spice warehouse are examined after a few frosty nights, numbers of the beetle will be found lying dead on the sills. It is most improbable, therefore, that *Araecerus* can maintain itself without re-importation under our conditions of climate.

The preliminary survey revealed the occurrence of *Araecerus* in African cacao and in nutmegs from Grenada and the East Indies. It is a serious primary pest of nutmegs, often causing severe damage to them ; but, apart from cacao, its presence has not hitherto been detected in products stored in the warehouses under consideration. Reitter, however (34), records it as imported into Germany with exotic fruits ; Bridwell (4) has found it in pods of *Pithecolobium* (*Samanea*) *saman* Benth. in Hawaii ; it is recorded by Tucker (42) as attacking maize stems in America, and the same writer states that in warm countries it is omnivorous ; MacGillivray (22) and Brown (5) both record its occurrence in strychnine ; Frederichs (13) notes it as a minor pest of coffee ; Ogilvie (30) gives records of it on papaw trees, in stored corn (probably maize), and associated with " black tip " disease of bananas ; Mayné (26) has found it attacking cacao pods on the trees in Belgian Congo ; and Zacher (46) records it in cacao and coffee beans, areca nuts, ginger, all kinds of drugs, dried fruit, maize, nutmegs and many kinds of seeds.

It is singular that while *Araecerus* was found abundantly in Grenada nutmegs, it occurred in only one of about a dozen consignments of Grenada cacao examined ; moreover, cacao and nutmegs from Grenada are often shipped together, sometimes in the same hold of the ship. It seems from this that *Araecerus* exhibits a very distinct preference for the nutmegs. In this connection it is interesting to note that in West Africa, where nutmegs are not grown, at any rate in sufficient quantities for export, *Araecerus* is quite content with a diet of cacao.

During the survey, *Araecerus* has also been noted in an isolated consignment of cacao from Panama ; and occasionally in cacao from

Ecuador, Venezuela and Ceylon. In some Samoan cacao the beans showed injury resembling that caused by *Araecerus*, but no beetles were found. Table II shows the extent of infestation of cacao by *Araecerus*, and the relatively considerable damage caused by it to cacao from the Gold Coast.

TABLE II.

Infestation by Araecerus fasciculatus *De G. of Cacao from different countries.*

Country.	No. of Bags examined.	Number of Bags containing traces of *Araecerus*.*
Cameroons	136	—
Ceylon	143	4 (3 doubtful)
Dominica	5	—
Gold Coast	392	205
Grenada	1,234	16
Jamaica	9	—
St. Lucia	295	—
St. Vincent	12	—
Samoa	200	5 (doubtful—one consignment)
Trinidad	292	—
Brazil	108	—
Costa Rica	94	—
Ecuador	127	3
Panama	52	52
Venezuela	182	8

* " Traces" includes larvae, pupae, adults or damaged beans.

It is quite evident from Table II that as yet the only country in which *Araecerus* has to be considered as a serious cacao pest is the Gold Coast, where a study of the beetle has recently been commenced by the Senior Entomologist at Aburi (Mr. W. H. Patterson). At the same time it is always possible, though perhaps unlikely, that in the future *Araecerus* may become important in other cacao-producing countries ; for example, in Panama. All the cacao from this country which was seen, though admittedly only a small quantity, showed damage by *Araecerus*.

The damage caused by *Araecerus* larvae to cacao beans is characteristic. There is usually a large exit-hole, while inside the bean a varying proportion of the cotyledons is replaced by the frass of the larva. The frass takes the form of a rather fine dust, often yellowish

in colour, and is entirely distinct from that of *Ephestia* larvae, whose frass appears as small nodules the colour of the cacao itself, adhering to strands of webbing exuded by the larvae as they move about. The beans are often considerably hollowed out by *Araecerus* larvae, not more than one of which is generally found in a single bean. Pupation as a rule takes place within infested beans, whereas in *Ephestia* the reverse is usually the case. The survey has demonstrated that *Araecerus* is introduced into Great Britain in larval, pupal and adult stages ; whether the eggs are also introduced is not yet known.

The question arises as to the possibility of re-infestation by *Araecerus* of cacao stored in the same warehouses as nutmegs, which, as has been shown, are often seriously infested by the beetle. From present knowledge of the incidence of *Araecerus* in this country, it seems that such infestation might be possible in the summer months, but that it is extremely unlikely to occur during the winter season, because of the apparent inability of *Araecerus* to withstand low temperatures. Whether the beetle breeds at all under British conditions of climate ; whether re-infestation of cacao from nutmegs does in fact occur, and whether, if so, it is likely to be serious, has yet to be discovered.

(*Note.*—Reh (33) gives a description and bibliography of *Araecerus* ; the eggs are described by Swezey (41), and the larvae and pupae by Cotton (7).)

(ii) *Corcyra cephalonica*, Staint.

Unlike *Araecerus*, this moth (family Galleriidae) has a comparatively wide distribution as a cacao pest. Although generally speaking it is found only in small numbers, its occurrence to a somewhat greater extent in one or two cacaos is interesting and important, because, as its English name of Rice moth implies, it probably occurred originally as a pest of rice, adapting itself later to other products.

There are very few records of its occurrence in England ; Meyrick (27) records it, however, from Kent, Middlesex and York, and states that it is an introduced species. Abroad, Zacher (46) notes its occurrence in the Mediterranean region, in India, Ceylon, Java, Western Sudan, Nyasaland, Réunion, Brazil, Cuba, Grenada, Porto Rico, Mexico, the United States, Hawaii, Germany and France ; de Seabra (12) records it from San Thomé ; Simonds (39) from Fiji ; Vayssière and Mimeur (43) from French West Africa ; and Ritchie (35) from Tanganyika.

Regarding its food, it appears to be fairly catholic in taste. Zacher (45) has taken it in large numbers from rice of various kinds, and records its occurrence in Germany in currants and other dried fruits ; Meyrick (27) notes it in England in dried currants ; Chittenden (6) records it in the United States in stored rice, all forms of cocoa and chocolate whether sweetened or not, ships' biscuits and sesame seeds, and is of the opinion that its habit of feeding on cacao-beans is probably an acquired one ; Hutson (19 and 20) mentions its occurrence in stored rice and stored cacao-beans in Ceylon ; Bedford (2) gives a record of its feeding on stored cotton-seed in the Sudan ; Simmonds (39) has found it in cotton-seed, linseed, cacao-beans, chocolate and rice in Fiji ; Roepke records it in husked rice and maize in Java ; and Ritchie (35) states that it is attracted to bulrush millet already damaged by the moth *Sitotroga cerealella* Ol.

The incidence of *Corcyra* in cacao imported into London and inspected during the present survey is best shown by Table III, which in its arrangement is exactly comparable to Table II.

TABLE III.

Infestation by Corcyra cephalonica *Staint. of Cacao from different countries.*

Country.	No. of Bags examined.	No. of Bags containing traces of *Corcyra*.*
Cameroons	136	11
Ceylon	143	6
Dominica	5	1
Gold Coast	392	1
Grenada	1,234	11
Jamaica	9	—
St. Lucia	295	34
St. Vincent	12	—
Samoa	200	8
Trinidad	292	5
Brazil	108	1
Costa Rica	94	2
Ecuador	127	—
Panama	52	—
Venezuela	182	—

* " Traces " includes larvae, pupae, adults and damaged beans.

It will be seen that except in the case of St. Lucia cacao, infestation by *Corcyra* is as yet almost insignificant. That *Corcyra* is an insect potentially dangerous to cacao is, however, demonstrated by the numerous records given above, wherein it is noted as of frequent occurrence in all forms of cacao in widely distant parts of the world.

Corcyra larvae damage cacao in the same way as *Ephestia*, and the description of damage to beans, given when discussing the infestation of cacao by *Ephestia*, applies equally to this species, except that the frass-nodules of full-grown *Corcyra* larvae are larger than those of full-grown *Ephestia* larvae. The life histories of the two species are very similar, but it is not yet known whether *Corcyra* is capable of withstanding the winter in Great Britain.

The cocoons of *Corcyra* are easily distinguishable from those of *Ephestia* ; they are constructed by the larvae when about to pupate, and consist of strong, thickly woven, very white silk, whereas those of *Ephestia* are smaller, thinly woven, greyish, sometimes almost transparent, and much less conspicuous. *Corcyra* larvae seem to be somewhat gregarious in their habits ; cocoons are frequently found not merely in close proximity to one another, but actually matted together, so that it is a matter of some difficulty to separate individual cocoons. Indeed, Zacher (45), in describing a bad infestation of cacao-powder by *Corcyra*, states that in this instance the surface of the powder was covered so thickly with cocoons, which formed almost a solid mass, that it was extremely difficult for the moths in the underlying cocoons to emerge from them at all. In the case of the comparatively mild infestation of cacao beans noted during the present survey, it was often by no means easy to disentangle the cocoons from the sacking upon which they were spun without injuring the enclosed pupae.

In regard to the incidence of *Corcyra* in the warehouses generally, it has been found in varying, but on the whole small, numbers in Grenada nutmegs, and is distinctly one of the less common of the warehouse insects. Its larvae have not been seen crawling over bags, walls, floor, etc., in large numbers in the autumn, as in the case of *Ephestia* larvae, nor was it recorded in the winter months, except as infesting newly arrived consignments of cacao or nutmegs.

Thus with *Corcyra* there is the same problem awaiting solution as with *Araecerus*, i.e. to determine whether it is capable of surviving the winter in this country ; whether it will breed here ; whether it will re-infest cacao in the warehouses ; and following from this, whether its incidence in nutmegs is of material importance to cacao.

(iii) *Ephestia elutella* Hb.

The Phycitid moth, *Ephestia elutella* Hb. is by far the most important of the various insects which infest stored cacao generally, though Patterson (32) considers that *Araecerus fasciculatus* De G. is the more important in West African cacao.

Ephestia elutella is found in varying and often large, numbers at the London wharves and warehouses, in cacao from all parts of the world. No cacao is immune from its attacks, though it appears to prefer some cacaos to others.

The geographic distribution of *Ephestia elutella* is very wide ; Zacher (45) mentions the moth as occurring throughout the warmer parts of Europe and extending as far north as the southern part of Sweden ; it has established itself widely in both Canada and the United States ; and Myers (29) has recorded it from Australia. During the survey it has been noted in cacao from many tropical countries, including Costa Rica, Panama, Brazil, Gold Coast, the Cameroons, Nigeria, Nyasaland, Ceylon, Java, Samoa.

It is, of course, the larvae which are responsible for the damage to cacao ; the moths themselves are incapable of taking solid nourishment. The types of food which these larvae will eat are most diverse, and it is this catholicity of taste which constitutes one of the chief reasons why *Ephestia elutella* is so important an insect economically.

Apart from cacao-beans, the larvae of *elutella* have been recorded in biscuits, figs and chocolate in England by Meyrick (27) ; in Australian currants by Myers (29) ; in ground-nuts in Nyasaland by Mason (25) ; in shelled walnuts in California by Maskew (23 and 24) ; in sugar in France by Smits (40) ; in cocoa-powder in Germany by Andres (1) and by Zacher (45 and 46) ; in earth-nuts, dried vegetables, rice, rhubarb-roots, bread, cakes, grain, pearl barley, dried apples and pears, orange-peel and all kinds of seeds and cereals in Germany by Zacher (45 and 46) ; in grain in England by Dendy and Elkington (10) ; in pea-nuts in America by de Ong (11) ; in different kinds of nuts in Canada and in linseed in British Columbia by Curran (9). Finally, Vecchi (44) avers that the larvae have been found feeding on dead but not yet desiccated individuals of the bee, *Apis ligusticus*.

Ephestia elutella is continually being introduced from abroad into the London warehouses, although it is not yet possible to state definitely that such introduction takes place throughout the year.

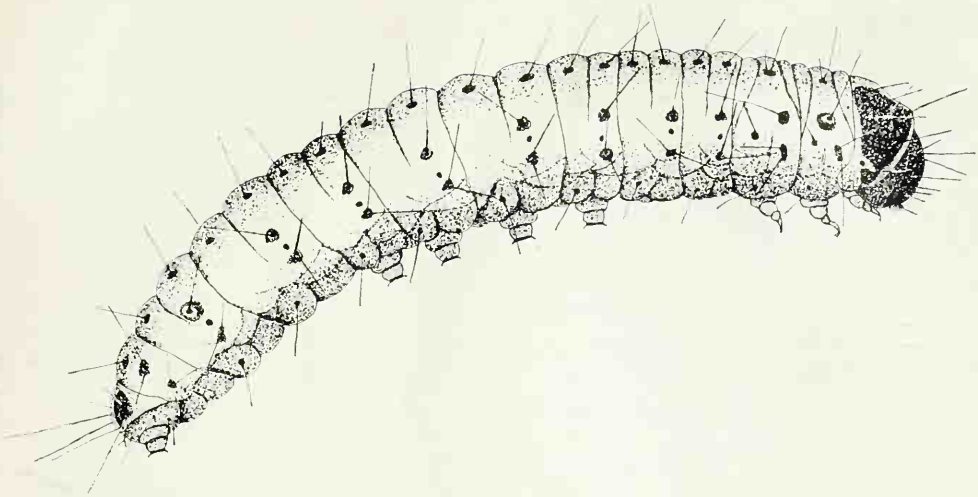

Fig. i.—*Ephestia elutella* Hb. larva. × 12 (approx.)

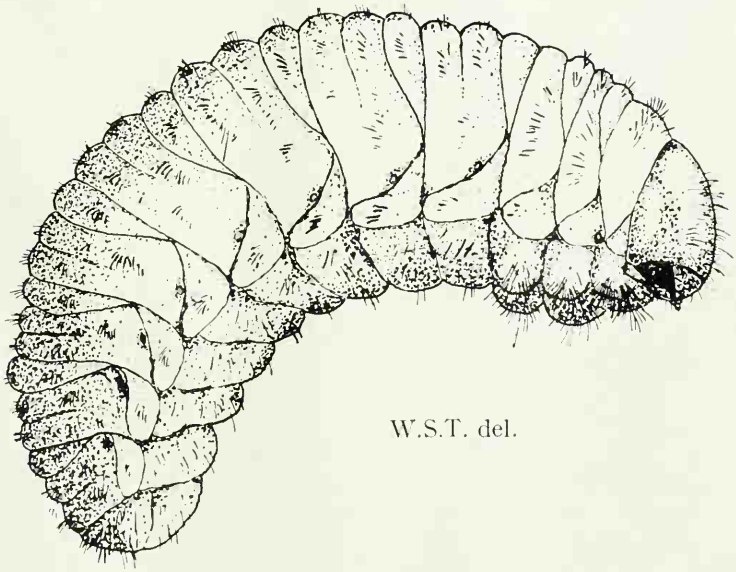

Fig. ii.—*Araecerus fasciculatus* de G. larva. × 12 (approx.)

PLATE III.

Table IV shows the number of bags of cacao examined, which were infested by *Ephestia* in the larval and the pupal state in each month.

TABLE IV.

Month.	No. of Bags examined.	No. of Bags infested by Larvae.	No. of Bags infested by Pupae.
April . . .	48	9	7
May	434	65	37
June	506	155	114
July	570	230	212
August . . .	258	98	67
September . . .	289	39	159
October . . .	175	39	36
November . . .	28	5	4
December . . .	240	31	46

During the period April to December, 1928, careful records were kept of the occurrence of larvae and pupae of *Ephestia elutella* in cacao arriving at the warehouses. These records show that the proportions of larvae and pupae were increasing at about the same rate, but that there was a constantly higher proportion of larvae. The larval peak was reached in July–August, after which there was a sharp drop. There was a slight drop in the pupal figure in August, followed by a high peak in September. By October, the proportion of pupae had fallen again till it was almost equal to that of larvae. From October to December the proportions fluctuated but at the same time approximated. There was thus a larval peak in July–August, followed by a pupal peak in September, which might be expected ; what takes place between December and April is of course, not yet known.

The succession of larvae and pupae, however, is not quite so simple as the foregoing appears to indicate. Within the period of the survey, *Ephestia* has been found to arrive in London most commonly as full or nearly full-grown larvae and as pupae. Sometimes infested beans on being opened have contained half-grown and occasionally quite young larvae, and sometimes a few adult moths have flown out when the bags were cut open, but these instances are comparatively rare.

On the other hand, large numbers of empty cocoons and pupa-cases have often been found on opening the bags. The inference is that the moths emerged from these cocoons during the voyage, and very probably laid eggs.

Now it is usually not until a considerable period of time has elapsed after egg laying that an infestation of cacao is noticed. The eggs and newly-hatched larvae, though visible to the naked eye, are so minute that in the ordinary way their presence is never detected. Moreover, almost the first act of a newly-hatched larva is to secrete itself within a crack in a cacao-bean, from which base it proceeds to eat its way into the centre of the bean, where it generally remains until fully or nearly fully-fed, unless circumstances demand its migration to another bean. Consequently, the cacao often appears clean until frass (excrement) is seen extruding from beans or until the larvae themselves are seen round the seams of the bags or crawling over the outsides in search of suitable places for pupation.

Thus moths which have emerged during the voyage, as evidenced by the empty cocoons seen round the seams of the bags, may very easily have given rise to a further infestation (re-infestation) which in fact commenced on board ship, but which, on account of the time that elapses before such infestation becomes apparent, is often attributed to conditions in the warehouses. That moths do emerge during transit was shown on 3rd September, 1928, when an inspection of cacao was made on board a ship immediately on arrival in the Thames ; on that occasion moths were noted flying above the bags of cacao in the hold.

It is apparent that primary infestation of cacao by *Ephestia* takes place abroad, and that the introduction of the moth to the London warehouses may take place by means of eggs, larvae, pupae or adults, but most obviously by means of larvae and pupae. It would appear that the first re-infestation of the cacao may take place on board ship during transit from abroad to the United Kingdom. The question of the incidence of *Ephestia* in cacao from different parts of the world now arises.

Table V shows the infestation of cacao from the various countries.

TABLE V.

Country.	No. of Bags examined.	No. of Bags showing infestation.
Cameroons	136	34
Ceylon	143	49
Dominica	5	5
Gold Coast	392	180
Grenada	1,234	298
Jamaica	9	6
Samoa	200	101
St. Lucia	295	202
St. Vincent	12	6
Trinidad	292	132
Brazil	108	9
Costa Rica	94	7
Ecuador	127	45
Panama	52	52
Venezuela	182	134

There is little information regarding variation in the duration of the life-cycle of *Ephestia* in the warehouses, but several important points have been brought to notice.

Ephestia seems capable of withstanding a considerable degree of cold. In the course of a visit paid to one of the cacao-warehouses about a fortnight after the intensely cold spell in December–January, 1927–28, a number of living *Ephestia* larvae were found hibernating between some sheets of brown paper which had been left lying on the window-sill. The larvae were fully grown and had spun cocoons, but had not pupated ; they seemed quite healthy, and when brought to the warmth of the laboratory soon began to leave their cocoons and to crawl about in a lively manner. Eventually they pupated and produced moths. On the same occasion many living larvae were found on the wall of one floor, where they had taken advantage of cracks in the mortar between the bricks. These larvae were also full-grown, and were evidently hibernating.

Waste products and rubbish of all kinds quickly collect in corners and along the bottoms of walls ; mingled with this refuse are nearly always some cacao beans, and the larvae of *Ephestia* have been found

feeding, not only in these beans, but also upon refuse generally. It is interesting to note that the larvae so found during February, 1928, were not yet fully-grown, nor did they appear to be definitely hibernating.

The evidence of the survey, and the long experience of the warehouse staffs, show that from about the end of June to about the middle of August, but particularly during July, the adult moths of *Ephestia* occur abundantly, often in such numbers as to become a serious nuisance. For example, at a warehouse visited frequently in July, 1928, and in succeeding months, there was stored on one floor a parcel of Guayaquil (Ecuador) cacao which arrived only the previous month. This parcel was the only one stored on that particular floor, and while the moths were common in most of the other floors, they occurred here in vast numbers. The females oviposited freely on the bags, and watch was kept on the pile. From the beginning of September and for a period of some weeks following, very large numbers of larvae emerged from the bags, crawling first to the top of the pile, which speedily became covered with a thick silken web, then down the sides to the floor, and across it to the walls, up which they climbed till they found suitable crannies for pupation, often among the rafters of the ceiling. There is little doubt that these larvae were the progeny of the swarm of moths noticed in July. If, as seems probable from finding healthy, hibernating larvae in mid-winter, these larvae from the Guayaquil cacao pupate in the spring of 1929, the resulting moths may prove the source of a definite warehouse re-infestation of cacao in the following July.

Questions have often been raised as to whether cacao which has been in store for a long time becomes seriously infected by *Ephestia*, and whether the degree of infestation increases in direct proportion to the period of storage. It is not yet possible to give satisfactory answers to these questions, because sufficient data are not at present to hand; what evidence there is, moreover, is somewhat conflicting. Judging from the evidence given in the previous paragraph, it would appear that the longer cacao remains in store, the more liable it becomes to infestation from moths which have accustomed themselves to a warehouse habitat. A special survey was carried out in October, 1928, in order to throw some light on this theory at a time when the larvae were still leaving the bags in search of suitable places for pupation; but the evidence obtained was inconclusive. In some cases 1927 cacao seemed to be more heavily infested than 1928; in

others the reverse. It must, of course, be recollected that there was variation as between cacao from different countries, but in the main it seemed to be cacao which had arrived at the warehouse between about January or February and July, 1928, that was the more heavily infested.

In considering these somewhat negative results, certain possibilities should be taken into account. It may be that after a certain time in store the moisture-content of cacao falls below that preferred by *Ephestia*, and so such cacao becomes distasteful. When selecting some cacao for experimental work on one occasion, a bag of Grenada cacao which had been in store for nearly three years was examined, and although abundant evidences of damage by *Ephestia* were present, there was no sign of life.

Further, a small wasp, *Microbracon hebetor* Say (Braconidae, Hymenoptera), which is a parasite of *Ephestia*, undoubtedly plays a large part in reducing the number of *Ephestia* larvae which are able to complete their life-cycle in the warehouses, and as Hase (17 and 18) points out, is a most useful auxiliary to mechanical control measures. *Microbracon hebetor* is referred to in greater detail later.

It is perhaps significant that the maximum infestation occurred on the whole in 1928 cacao which arrived at the warehouse up to July, while that stored after July seemed in general to be considerably less heavily infested, with exceptions in both cases however. It will be remembered that July is the month when the adult moths are most abundant in the warehouses. From the occurrence, already referred to, of the heavy larval infestation of Guayaquil cacao at another warehouse, following the July peak, it is not unreasonable to suppose that the bulk of the larvae seen during the special survey to be leaving the cacao stored from January to July, 1928, were the direct result of the July flight of moths.

Thus it may be that serious warehouse infestation is liable to occur mainly in cacao stored say from January or February to July or August in one year, while older and more fresh cacaos, the former through lack of moisture and the latter through escaping the July flight of moths, tend to remain more free from infestation.

Turning now to the habits of *Ephestia*, the most noticeable characteristic of the moths themselves is perhaps their aversion from light. Almost always they seek out the darkest parts of the floors ;

during the flight period in July, 1928, large numbers could be seen resting on the more shaded walls of the floor on which the Guayaquil cacao already referred to was stored, but very few indeed were to be found upon an adjacent window. This habit, however, is probably modified to some extent by the position of the cacao. In the case of the Guayaquil cacao, no other product was stored on the same floor, and not more than a fifth of the total space available was occupied. Only one side and the back of the pile were sheltered from light. The moths, while preferring the darker portions of the walls nearest the cacao, and the darker sides of the bags themselves, never flew far away from the pile, and took no advantage of a distant but even more shaded corner of the floor. When not resting on the bags or on the adjacent walls they hovered about in the immediate vicinity of the cacao.

The same habit of shunning light is also characteristic of the larvae. When these leave the bags to pupate or hibernate as the case may be, they immediately seek those surfaces which face away from the light ; for every larva crawling over a surface exposed to light, a dozen or so may be found on a sheltered surface.

When wandering, the larvae often try to reach a comparatively high altitude. Many are not satisfied merely with the top of a pile of bags—probably, of course, owing to lack of suitable accommodation—and laboriously descend to the floor, crawling over it until some perpendicular surface is reached. At the same time, they do not appear to exhibit much consistency in regard to the height to which they finally ascend. Some are content to make their cocoons between the bags in the top two layers in a pile five or six feet high, sometimes lower ; others, having reached a wall, do not climb very high should a suitable cranny present itself ; others, again, climb to the ceiling, some ten feet or so above the floor, and might go higher if they could ; but all agree in showing the climbing and wandering instincts. Hence in considering warehouse hygiene, no part of a floor can safely be deemed immune from intrusion. It is possible that there may be a fairly well-defined period during which the wandering and climbing instincts assert themselves, and that after this period has passed, the larvae make use of the nearest suitable cranny, irrespective of its position. If this is so, the distance to be covered by each larva would be a limiting factor in regard to the ultimate height attained, and would explain the inconsistency just referred to.

As to the feeding habits of *Ephestia* larvae, it has already been said that on hatching from the egg, the young larva's first instinct is to hide. Having once secreted itself within a crack in the husk of a cacao bean, it seems rarely to leave its shelter until fully-grown, and not always then. When an infested bean is opened, the larva is nearly always found lying in the centre, and this seems to be the normal position. The cavity made by the larva becomes filled with small excretory nodules, which are characteristic, and which are usually loosely bound together by silken webbing. The presence of these nodules extruding from the end of a bean is a sure sign that *Ephestia* has been at work, though at this stage it is unusual to find the larva in situ, except in certain cases where, contrary to usual habits, pupation takes place inside the bean. It is of common occurrence to find beans which consist only of husk, excreta and webbing, the whole of the contents having been devoured.

Length of Life Cycle of Ephestia *in the Warehouses.*

This is a question concerning which there is still much uncertainty. Mention has already been made of the re-infestation of cacao on board ship during transit, resulting sometimes in the introduction of comparatively young larvae into the warehouses ; of the July flight of moths followed by the appearance of wandering larvae in abnormal numbers in September and October ; of the hibernation of fully-grown larvae in the warehouses during the winter ; and of the detection, also during the winter, of younger larvae subsisting on refuse and waste cacao, and, in a few instances, in bags of cacao. Very much more evidence than this is necessary before any definite statements can be made ; it is by no means certain what effect British climatic conditions have upon larvae introduced from abroad at different times of year, save that these conditions probably retard development.

The problem is a very complicated one. From the evidence at present to hand it might be assumed that the larvae resulting from the July moths, having passed the winter in hibernation, pupate in the spring and produce large numbers of moths the following July. But enormous numbers of these larvae are destroyed before hibernation by parasites, and the numbers which survive do not seem high enough to correspond with the numbers of moths seen in July. Again, as in the case of the Guayaquil cacao referred to, many of the moths comprising the July flight are undoubtedly of very recent introduction.

Moreover, moths were observed continuously from May to October, though mostly in comparatively small numbers. Some of these are introduced, but it is possible that some are the result of warehouse infestation, perhaps indeed that of the previous July. This suggestion is put forward on the grounds that, as biological experiments now in progress show, there is a quite definite inconstancy in the rate of development of individual larvae. Some feed up much more quickly than the majority, others much more slowly. Hence some of the progeny of the July infestation may feed up quickly and emerge in October, the majority may emerge in the following May, June or July, while others may take longer still to complete the cycle.

As stated when discussing the extent to which infestation by *Ephestia* takes place at different times of the year, larvae and pupae are being continually introduced. It is not known to what extent the development of these is hindered by the cool climate of Great Britain, but it is conceivable that those introduced in the autumn and winter are retarded long enough to swell the ranks of the next July flight, while those introduced in spring and summer may form not only the greater number of the July moths but also the majority of those seen in May, June, late August and September.

Until, however, the effect of climate upon *Ephestia* has been studied further, no exact information as to the life-cycle of the moth in this country can be given. Such study, of course, will have to be pursued at the warehouses, since the conditions prevailing in them cannot be properly imitated in the laboratory. Meanwhile experiments are in progress to observe and record in detail the life-cycle of *Ephestia* at a fairly constant temperature and humidity. Even under these favourable conditions the variation in the rates of development of individual larvae is surprising, and it may be that under warehouse conditions this variation is still more pronounced. Further work on the problem just set forth is, therefore, imperative.

As stated previously, *Ephestia elutella* is liable to severe attacks by a small wasp, *Microbracon* (*Habrobracon*) *hebetor* Say (Braconidae Hymenoptera), which often destroys large numbers of the larvae, According to Hase (17)* the larvae of Habrobracon are either biophagous or necrophagous, and larvae which are more than half-grown

* Hase worked with *Habrobracon brevicornis* Wesm., using *Ephestia Kühniella* Zell. as his host, but it has been shown by Muesebeck (28) that " references in literature to *Bracon* or *Habrobracon brevicornis, hebetor* or *juglandis* as parasites of the Mediterranean Flour Moth, *Ephestia Kühniella* Zell ..... concern this species ", i.e. *Microbracon* (*Habrobracon*) *hebetor* Say.

are preferred to smaller larvae. When fully-grown, the *Microbracon* larvae spin small, oval, white cocoons, which are often seen in large numbers near the shrivelled remains of their hosts.

The adults seem to be most numerous in September and early October, when the fully grown *Ephestia* larvae have commenced wandering. Many which have not already been parasitised are then stung, but oviposition does not appear to take place, for the host larvae die almost at once. So badly, sometimes, does *Microbracon* attack *Ephestia* larvae at this time, that their dead, flaccid bodies appearing as if their backs had been broken may be seen in hundreds, adhering to bags of cacao and to the ceilings. As a further example of the destruction sometimes wrought by *Microbracon*, the case may be cited of a considerable quantity of *Ephestia* larvae which were collected at the warehouses in the early autumn of 1928, and brought to the laboratory. Almost every one of these was parasitised, and only a very few eventually pupated.

From these instances it becomes apparent that when *Microbracon* occurs in large numbers, not only are its larvae instrumental in reducing the proportion of *Ephestia* larvae which would otherwise pupate and produce moths, but its adults play an even more important part by stinging and killing fully-grown, wandering larvae. Thus *Microbracon* may sometimes be a potent factor in reducing warehouse infestation in the spring and summer following its attacks in the previous autumn.

Much work is necessary before definite statements can be made upon the life-cycle and many of the habits of *Microbracon* under British climatic conditions ; moreover, the possibility of its use as a biological control against *Ephestia* in the warehouses is as yet an unexplored field of research.

Microbracon is probably parasitic on many moths belonging to the family Phycitidae ; it has been recorded by Myers (29) and Parker (31), as attacking *Plodia interpunctella* Hb. and *Ephestia cautella*, Walk., both of which infest dried fruits.

Another insect which seems to attack both *Ephestia elutella* and *Corcyra cephalonica* Staint. is *Holepyris hawaiiensis* Ashm. (Bethylidae, Hymenoptera), adults of which have been taken in bags of cacao which were infested by the larvae of these moths. *Holepyris*, however, is by no means common, as compared with *Microbracon*, and at present cannot be considered important, whatever it may become in the future. It is interesting to note that Bridwell (3) records *Holepyris*

as abundant in warehouses in Hawaii. The same author also records that in captivity it will oviposit in the larvae of *Plodia interpunctella* Hb. and *Corcyra cephalonica*, Staint.

IV. EXPERIMENTAL WORK IN CONNECTION WITH THE SURVEY.

Biological.

Work is now in progress upon the biology of *Ephestia elutella*, and two lines of research are being pursued ; one, a study of the structure of the adult moths, in relation to other species of the genus, concerning which there exists much confusion ; the other, a study of the life-cycle of *elutella*, both in relation to that of other species of the genus and to varying types of food. It is hoped eventually to publish the results of these investigations in the appropriate journals.

Large stocks of *Ephestia elutella* and other insects are being built up for experimental purposes, since much of the research necessary for a solution of the problems in connexion with stored products insects entails experimental work bearing on sterilisation and fumigation methods, and biological experimental work in relation to temperature, humidity and food.

Since the main object of the survey was to study the incidence of *Ephestia* in cacao arriving in London, no experiments on control measures have been specially planned at this stage. The two following experiments were conducted under special circumstances and are cited merely to give an indication of the nature of control work generally.

An experiment was arranged in June, 1928, to test the efficacy of hydrocyanic acid gas (HCN) in the form known as Zyklon B, as a fumigant against *Ephestia*. At the invitation of Messrs. Weber, Smith and Hoare, Ltd., the experiment was carried out in one of their warehouses in collaboration with the London Fumigation Co. and with the Cocoa, Chocolate, Sugar, Jam and Confectionery Trades' Research Association. The scope of the experiment was limited by insufficient supplies of the various stages of *Ephestia*.

The objects of the experiment were to test penetration of the gas into bags of cacao beans when stacked in piles ; to test the effect of the gas on warehouse insects in general and on *Ephestia elutella* in particular, and to test its effect on various foodstuffs.

It was proposed at first to fumigate a ground floor, but on account of the difficulty of satisfactorily ventilating this floor afterwards, a higher and more easily ventilated floor was selected.

For purposes of fumigation, circulation of air between the floor and the outside atmosphere was prevented by pasting strong paper over all window, loop and other door joints, ventilators and cracks. The actual floor and the ceiling were of concrete, the walls of brick, and there were double doors of iron.

In regard to interior arrangements, in order to restrict the circulation of air as much as possible, the cacao was piled in a corner formed by a side-wall and a buttress to which the doors were attached. Because infestation in the cacao used was on the whole slight, and because this infestation consisted almost entirely of larvae and pupae, nine bags were specially selected and labelled. Into the centre of each bag a small cage containing living *Ephestia* moths was introduced, together with a small tube in which was a test paper soaked in a solution of benzidene acetate and copper acetate (Sievert's and Hermsdorf's Test). Five of the bags so treated were from St. Lucia, and arrived in 1928; the other four were from Grenada, and had been in store since 1925. These nine bags formed part of the inner base of the pile, being placed at and near the corner before mentioned.

To test penetration of the gas, three other bags of cacao were placed in a convenient position, and each was fitted with an aspirator, the receiving tube thereof being driven into the centre of the bag. To the outlet tube of each aspirator was attached a length of rubber tubing, which was passed through the latch-holes of the double doors, outside which was arranged apparatus for testing the amounts of gas present in the bags while fumigation was still in progress.

In addition to these arrangements one bag of cacao infested by *Ephestia* larvae was divided into two parts which were re-bagged. One part was fumigated, the other retained as a control. Both were afterwards sent to the laboratory for examination.

Immediately the fumigant had been applied the operators left the floor, the doors at once being closed and pasted up from outside. Fumigation commenced at 11.30 a.m.; tests of the penetration of the bags by the gas during the experiment were made at 5 p.m. by means of the apparatus described above, when the gas was found to have penetrated to the centres of the bags. The floor was re-opened at 8.30 p.m. the same day, after fumigation had continued for 9 hours. The concentration of gas in the warehouse was approximately 1·5% by volume.

In estimating the effect of the gas on *Ephestia*, it should be noted that it was not possible to examine every infested bean from the nine bags of cacao referred to. Accordingly about 1½ lbs. of infested beans were removed from each bag, and the number of larvae and pupae found in each of these samples was recorded. It is interesting to note, in view of the theory put forward when discussing the question of the relation between the age of cacao-beans and the degree of infestation by *Ephestia*, that examination of the samples from the four bags of Grenada cacao, which had been nearly three years in store, revealed no larvae or pupae at all. These results are embodied in Table VI, and those of absorption of the gas by various products in Table VII.

TABLE VI.

Result of Fumigation of Cacao-beans. (*Based on 1½-lb. samples.*)

Bag.	Country.	Larvae.		Pupae.		Adults.		Percentage Kill.		
		Living	Dead	Living	Dead	Living	Dead	Larvae	Pupae	Adults
1	St. Lucia	–	59	–	2	–	–	100	100	–
2	Grenada	–	–	–	–	–	8	–	–	100
3	,,	–	–	–	–	–	33	–	–	100
4	,,	–	–	–	–	–	3	–	–	100
5	,,	–	–	–	–	–	6	–	–	100
6	St. Lucia	–	49	–	2	–	5	100	100	100
7	,,	3	49	–	3	–	5	94	100	100
8	,,	–	61	–	3	–	6	100	100	100
9	,,	–	34	–	4	–	8	100	100	100
10	,,	–	133	–	4	–	1	100	100	100

TABLE VII.

Absorbtion of HCN by Cacao in comparison with other Products.

Amounts of HCN in parts per million found in materials immediately after ventilation of premises.

Cacao Beans	12	Marshmallows	6
Cacao Powder	63	Dates	5
Agar Agar	3	Brazil Nuts	13
Gelatin	2·5	Walnuts	50
Chocolates (Liqueur)	2·5	Desiccated Coconut	15
Chocolates (Assorted)	1	Fruit Jellies (Sweets)	7
Chillies	15*		

* This figure represents the amount retained a fortnight after the experiment.

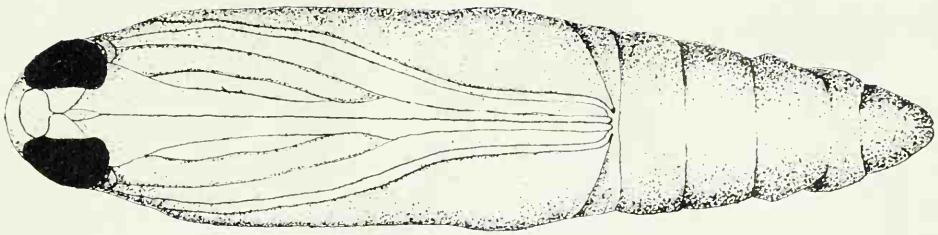

Fig. i.—*E. elutella*, pupa. × 12 (approx.)

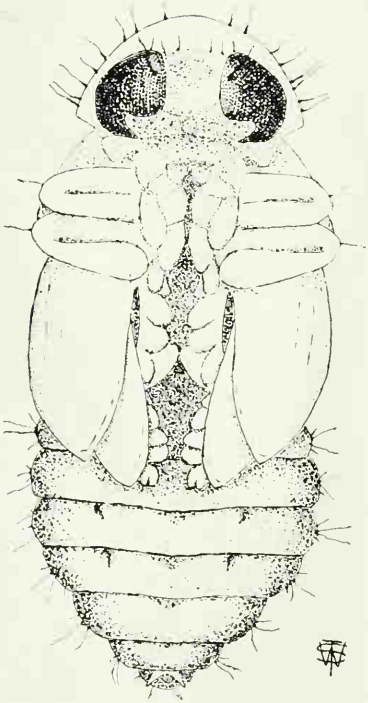

Fig. ii.—*A. fasciculatus*, pupa. × 12 (approx.)

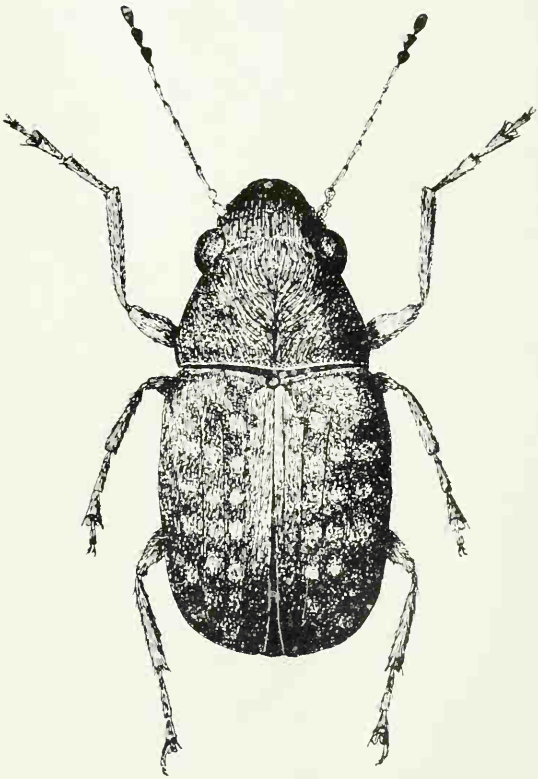

Fig. iii.—*A. fasciculatus*, adult. × 12 (approx.)

PLATE IV.

Cacao beans, it will be noted, absorb a relatively low amount of HCN. Even if this were not so, it is probable that the use of HCN would be safe as a control measure against *Ephestia* because the roasting undergone by the beans during manufacture into cocoa or chocolate would eliminate any gas absorbed. In connection with this experiment brief mention should be made of work done in America by Griffin and Back (15) and by Griffin, Neifert, Perrine and Duckett (14), on the absorption and retention of HCN by fumigated products, as a result of which work much interesting and valuable information has been obtained.

Further experiments, designed to provide a means of dealing with sudden outbreaks of *Ephestia* in warehouses over a limited period, were carried out in September, 1928, in collaboration with the warehouse authorities. The infestation upon which these experiments were made occurred in the warehouse during June, 1928, in Guayaquil cacao referred to in this report when discussing the July flight of moths and their offspring.

While the larvae were leaving the bags in September, the warehouse staff kept one man employed almost continuously in sweeping the floor and walls, but the larvae were present in such numbers that by the time the whole wall had been swept down it was necessary to begin the operation afresh. Even so, many larvae escaped through having already reached the beams in the ceiling. Moreover, this method of reducing the numbers of the larvae could only be used through the day.

Spraying with a proprietary wash was also employed, but while destroying such larvae as it actually touched, it did not seem to possess much power as a deterrent, since walls which had recently been sprayed offered no obstacle to other larvae, which climbed them freely. Continual spraying was, therefore, necessary. It was not considered safe to spray the bags themselves in case of damage to the cacao.

Again, the warehouse staff placed numerous pans of water in suitable positions round the pile. Larvae falling into them were drowned, but it was impossible to provide sufficient pans to make any real impression on the numbers of the larvae. In this connection it is interesting to note that one pan, measuring approximately 8 inches in diameter by 4 inches in depth, and placed at the corner of a bag where a strand of webbing used by the larvae in their travels reached the floor, was after 24 hours completely filled with drowned larvae.

Experiments were then made with a form of grease-banding analogous to that used for fruit trees. At first a mixture of three parts of resin to one part of linseed oil was used. The mixture was smeared on strips of paper which were fixed round the walls in a continuous band. This mixture proved unsatisfactory, because when cold it tended to harden, and thereby allowed the larvae to negotiate it successfully.

Another attempt was made with a second preparation smeared on grease-proof paper which was pasted to the walls in a continuous band, and which was also placed round the pile of bags. In regard to adhesiveness, this preparation was successful, but its very success became a serious disadvantage, because the bands became after a time so clogged with bodies that fresh larvae were able to cross with impunity, and so to escape. This method of trapping the larvae has the merit of being relatively inexpensive, but the question of re-application has to be considered when the infestation, as in this case, is a particularly bad one.

V. SUMMARY.

The survey of insect conditions prevailing in the London wharves and warehouses shows that there is considerable infestation of the cacao on arrival.

The chief insects found infesting cacao are *Ephestia elutella* Hb., *Araecerus fasciculatus* De G. and *Corcyra cephalonica* Staint. Of these *E. elutella* is the most important.

Cacao from all exporting countries shows evidence of insect infestation, which takes place in these countries. Infested cacao arrived during each month of the period covered by the survey, and the period of maximum infestation extended from July to October.

It should be noted that the Anthribid beetle *Araecerus fasciculatus* De G., though frequently found in West African cacao, is absent from most other cacaos. It occurs abundantly in nutmegs from Grenada (B.W.I.), but Grenada cacao is apparently almost free from its attacks.

It is difficult, if not impossible, at this stage of the investigation to assess the loss caused by insect infestation of cacao. It can be said, however, that while the wharfingers and brokers are affected to a relatively slight extent, the merchants, and particularly the cocoa

and chocolate manufacturers, sometimes suffer considerably. Apart from the actual loss caused by cacao-beans being destroyed or eaten by insects, indirect loss caused by fouling of the cacao is important, and there is the serious risk of loss of prestige incurred by manufacturers who inadvertently sell chocolates or other goods harbouring insect larvae. The attitude of the Food, Drug and Insecticide Administration of the U.S. Department of Agriculture shows the attention paid to insect and fungus infestation of cacao imported into America.

Remedial and control measures to be effective must begin in the exporting country. In this country only palliative measures can be adopted pending further knowledge of the habits and life history of *Ephestia* under the peculiar climatic conditions prevailing in the London wharves and warehouses.

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